LOAD PAD DEVELOPMENT FOR RESEARCH AIRCRAFT WING STRAIN GAGE LOADS CALIBRATION TEST*†

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Abstract

An elastomeric tension-compression load pad material was selected in preparation for ground loads testing of a research aircraft. Five rubber materials candidates were load tested for ultimate tensile strength, creep strength, low-cycle fatigue strength, and compressive stiffness. Additionally, two bonding agents candidates were tested for strength properties, ease of application, removal, and reliability. Material testing was completed at NASA Dryden Flight Research Center to select a load pad material and a bonding agent capable of providing the elastomer interface for the aircraft while enduring both tensile and compressive applied loads.

Introduction

In the ground-testing phase of a flight research aircraft program, frequently a loads test is required prior to flight to verify analyses and calibrate the instrumentation installed on the airframe. When applying flight loads to the wing surface, an elastomer interface between the wing surface and the loading mechanism is essential to ensure an even load distribution over the wing and to prevent damage to the vehicle during the loads calibration test. In preparation for the wing strain gage loads calibration test[1] on the Active Aeroelastic Wing (AAW) of a modified F-18 flight research aircraft at NASA Dryden Flight Research Center, Edwards, CA[2,3], materials testing was completed to develop suitable load pads and a bonding agent for the load induction points. These load pads of various sizes covered 60 percent of the AAW lower wing surfaces and provided the elastomer interface on the aircraft for the tensile and compressive applied loads. Figure 1 shows the right wing of the AAW setup for the loads test with the load pads bonded to the lower surface of the wing.

The objectives of this load pad development research were to identify an elastomer interface material and a bonding adhesive that could be used for the AAW loads calibration test. The scope of this paper discusses the material identification, tests conducted, and the results that led to the load pad material and bonding agent selection.

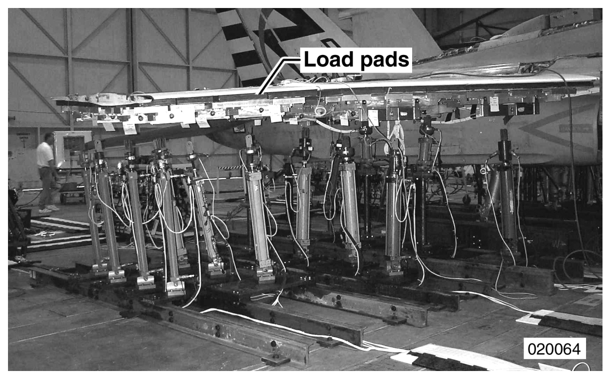

Figure 1. The AAW wing strain gage loads calibration test setup.

Material Identification

Material research began from an understanding of the materials used in past NASA loads tests and commercial tests. The desired load pad and adhesive characteristics included:

- Load Pads: Elastomeric material with a 2-inch thickness, moderate compressive stiffness, and high tensile and creep strength characteristics.

- Adhesive: Adequate bond strength, removable adhesive with rubber, metallic, and composite bonding capabilities that can withstand low-cyclic loading.

To identify the load pad material, five types of neoprene foam or sponge rubber (Table 1) ranging from 1-inch to 2-inch thicknesses and varying durometer (hardness of the material) scales were tested. Two bonding agents (Table 2) were utilized throughout the testing and played an important role

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Table 1. Neoprene pads tested.

Pad No.	Pad Type	Thickness, in.	Durometer
1	Super soft pad[‡]	1	5-10 (shore A)
2	Standard pad[§]	2	10-30 (shore OO)
3	High grade soft pad[‡]	1	40 (shore A)
4	Standard pad[¶]	1	50 (shore OO)
5	Firm pad[§]	1.5	30-50 (shore OO)

[‡]McMaster-Carr (Santa Fe Springs, California)
[§]Rubberlite (Schnecksville, Pennsylvania)
[¶]Belko (Kingsville, Maryland)

Table 2. Bonding agents tested.

Agent No.	Bonding Agent	Advantages	Disadvantages
1	1300 Rubber and Gasket Adhesive[**]	Rubber adhesive	• Difficult to work with • Required solvent out-gassing to bond • Difficult to remove
2	B-1/2 Polysulfide Fuel Tank Sealant	• Gap-filling • Fuel resistant • Easy to work with • Chemical bond • Removal experience	Unknown rubber bonding capabilities

[**]3M (St. Paul, Minnesota)

since the AAW loading requirements included not only compression loads, but also tension loads. The tensile loads pull down on the lower wing surface; therefore, both the load pad material and the bonding agent must withstand the applied tensile loads.

Test Approach

The four materials tests were conducted at the NASA Dryden Flight Loads Laboratory. These tests aided in identifying the appropriate load pad material and bonding agent for compressive stiffness, creep strength, ultimate tensile strength, and low-cycle fatigue strength testing. Initially, all five neoprene pad types were to undergo the testing, but as different pads began to fail the requirements for the AAW loads test, these were eliminated from the testing matrix.

The compressive stiffness testing was performed to ensure the selected pad material had a capable stiffness and spring rate to evenly distribute the applied load in order to prevent high-pressure hotspots on the wing surface.

The testing was done in a materials testing machine which applied up to 3,000 lb on a 10-in. by 12-in. pad area, sandwiched between two steel plates connected to the machine. Bonding agents were not examined during this test. The 3,000 lb correlated to 25 lb/in^2, which was the AAW projected maximum compression pressure. The loading rate was set at 25 lb/sec for both loading and unloading. The profile stepped through 10, 20, and 25 lb/in^2, with the loads held for one minute each, then returned to zero for a one-minute hold before proceeding to the next load. Pad deformation and loads were recorded during each test.

Creep testing was performed to ensure the load pad could sustain a prescribed load for a predetermined period of time since the AAW test configuration required the load pads to support loading hardware for up to a two-month testing period. The creep testing was done in a structural frame where several 6-in. by 6-in. specimens hung for up to eight weeks with a 500 lb deadweight load producing 14 lb/in^2 stress. The specimens were prepared by bonding both sides of the neoprene pad to 0.5-inch aluminum plates. Pad elongation was measured during the period of time the specimens carried the 500 lb load.

The AAW maximum planned tensile testing stress corresponds to 25 lb/in^2. The goal was to demonstrate a factor of safety (FS) of 3 with ultimate tensile strength testing. Ultimate tensile strength testing was done in the materials testing machine, which applied up to 10,800 lb on a 12-in. by 12-in. specimen (Fig. 2). Each testing specimen was prepared by bonding both sides of the neoprene pad to 1-in. thick aluminum plates. The loading rate was set to 25 lb/sec for both loading and unloading. The loading profile stepped through 10, 20, 25, 50 and 75 lb/in^2. Each load plateau was held for one minute before proceeding on to the next load point. Each specimen was loaded to failure, while pad elongation and loads were recorded during these tests.

Figure 2. Load pad ultimate tensile strength test setup and pad failure.

Low-cyclic testing was conducted to show both rubber and bond reliability with the AAW predicted maximum compressive and tensile loads. The cyclic testing was also done in the materials testing machine with 6-in. by 6-in. and 12-in. by 12-in. bonded specimens. The load rate was set to 125 lb/sec and 100 complete cycles were done with ten seconds hold at both plus and minus 25 lb/in^2. One hundred load cycles was chosen based on the estimated number of load cycles required for the AAW calibration test. Pad elongation and deformation measurements were correlated to the applied load.

Test Results

During material testing, the specimen preparation for bonding the neoprene pad to the aluminum plates greatly influenced the results of the creep, ultimate strength, and cyclic tests. A proper surface preparation and bonding process proved to be essential in avoiding premature failures in tension.

The compression test determined the pad deformation and stiffness (i.e. modulus of elasticity) under compressive loads. Determining the load pad modulus of elasticity (Young's Modulus) was necessary for a finite-element analysis that studied the AAW expected peak surface pressures on the wing. Results showed modulus of elasticity for the pads were nonlinear, which is typical for elastomeric material. Figure 3 shows the stress compared to the strain curve for pad 5, in which five linear curve fits were done over different pressure ranges to determine Young's Modulus. The pad deformations from all five pad types ranged from 0.04 in. to 1.02 in. under the AAW expected maximum compression pressure of 25 lb/in^2.

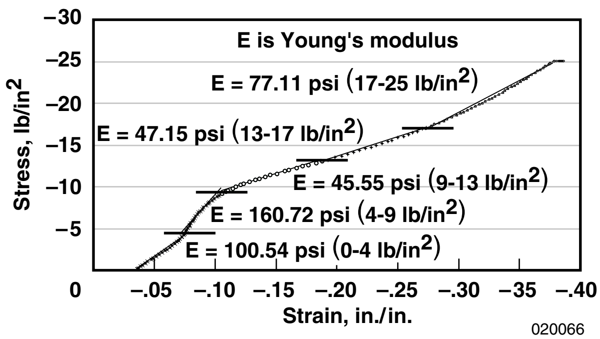

Figure 3. Stress compared to strain results for compression test of pad 5.

The creep test determined if, and how long, the load pad could be placed under 500 lb of tensile load for a period of time without tearing or splitting apart. This test was conducted in parallel with the ultimate strength testing. The overall pad selection matrix was quickly narrowed down to pad 4 or 5 as a result of premature creep failures. Table 3 shows the endurance times and the failure modes which occurred. Pads 4 and 5 never experienced a failure during the eight weeks of continuous load testing. The creep elongation of 0.32 in. for pad 5 occurred during the first 10 days and then remained constant for the remainder of the eight weeks.

The ultimate tensile strength test determined which load pads could withstand sufficient tensile loads without failure and provided confidence in the bonding reliability of the adhesive. Table 4 displays the ultimate tensile strength of the pads taken to failure. As noted in that Table, a FS of 3 was not attained. However, lowering the FS goal to 2 was acceptable because of the benign failure consequence of the AAW testing configuration and the Flight Loads Lab standard factor of safety practice. This safety practice requires a FS of 3 only for untested designs and a FS of 2 for tested designs. Therefore, pad 4 and 5, as tested designs, both remained in the running for the AAW load pad material.

As the specimens for the cyclic testing were being prepared, some experimental processes were being developed for removing the bonded pad and plates, because no adhesive residue could be allowed to remain on the wing surface of the AAW aircraft. During the removal efforts, bonding agent 1 was eliminated because of intense labor to remove it and

Table 3. Creep test results over an eight-week time period.

Pad No.	Thickness, in.	Agent No.	Failure Mode	Failure Time	Pad Elongation, in.
1			No creep testing done		
2	2	1	Rubber	26+ hours	0.51
2	2	1	Rubber	3 hours	0.47
3	1	1	Adhesive	30 minutes	0.02
3	2	1	Adhesive	60 minutes	0.13
4	1	1	No failure	No failure	0.236
4	2	1	No failure	No failure	0.387
5	1.5	1	No failure	No failure	0.323
5	1.5	2	No failure	No failure	0.334

Table 4. Ultimate strength testing failure pressures.

Pad No.	Thickness, in.	Agent No.	Failure Mode	Failure Stress, lb/in^2
1		No ultimate strength testing done		
2	2	1	Rubber	38
3	1	1	Adhesive	19
4	1	1	Adhesive	42
4	2	1	Adhesive	50
5	1.5	1	Rubber	50
5	1.5	2	Rubber	55

stubborn residue remaining on the surface. Pad 4 was also eliminated because of difficulty in removing the material.

Therefore, the low-cycle fatigue strength testing was done only on pad 5 with bonding agent 2, to demonstrate the pad and bond reliability in compressive and tensile cyclic loading. Cyclic testing confirmed pad 5 and bonding agent 2 could withstand 100 cycles of the AAW planned maximum compression and tensile loads.

Summary

The material testing research led to the selection of a load pad material and bonding agent which met all the material properties required for the AAW loads calibration test. The chosen pad was number 5, a firm 1.5-inch-thick neoprene rubber, of 30 to 50 durometer hardness on the Shore OO scale, with no skin sides. Under compressive loads the Young's Modulus was non-linear and this pad deflected 0.6 in. at 25 lb/in^2, which was the maximum compressive pressure during the AAW loads tests. During tensile loading, the pad elongated 0.2 in. at 25 lb/in^2, which was the maximum tensile pressure for AAW loads tests. Bonding agent number 2, B-1/2 polysulfide fuel tank sealant, proved reliable. This agent turned out to be gap filling, more reliable, and easier to remove than previously used contact cement adhesive.

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[1]Lokos, William A., Candida D. Olney, Tony Chen, Natalie D. Crawford, and Rick Stauf, "Strain Gage Loads Calibration Testing of the Active Aeroelastic Wing F/A-18 Aircraft," AIAA-2002-2926, to be presented at the 22nd AIAA Aerodynamic Measurement Technology Ground Testing Conference, June 24-27, 2002, St. Louis, MO

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